Improved Cu Abrasive-Free Polishing at 0.13um Manufacturing and Beyond

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Abstract

Abrasive free polishing (AFP) for 0.13 um node Copper damascene interconnects was improved. A CMP process using the modified groove design pad to provide optimized polishing friction force can reduce a metal loss of 20% on Cu wiring, compared to the conventional AFP process. We demonstrated meeting the planarity target for a 0.1um technology node without extra intermediate oxide polishes.

Introduction

A continuing reduction in device dimensions requires the use of both copper (Cu) metallization and low-K dielectrics to the interconnect delay. One of the biggest challenges to integrating Cu dual-damascene is Cu chemical mechanical polishing (CMP). The first step in Cu CMP is to remove the bulk of copper that collects on the underlying diffusion barrier. The second step can be conducted using a selective or non-selective approach. The selective approach preserves the copper and oxide, but can lead to excessive dishing and erosion. The oxide erosion between Cu lines is attributed to the depression depth of the lines. We must use oxide CMP for at least every other device layer to implement the fabs.The non-selective approach provides good planarity in eliminating the intermediate oxide polish. But it is more expensive because of a higher copper loss requiring us to start with more copper and oxide. The choice between the two approaches depends on how well the first step can be accomplished.

We present results on the planarity of copper interconnects using abrasive free polishing (AFP) solutions [1-3] along with staked pads. AFP's strength is its insensitivity to over-polishing allowing for an extremely wide polish window with little metal loss. This report describes the use of AFP as the first step in dual-step CMP and the development of synergistic consumable sets such as slurries and pads for specific application.

Experimental

A short yield of submicron Cu wiring in the second metal layer is shown in Fig. 1. The test pattern was on 0.25 um line/0.25 um space comb structures of the second level of metallization. As the depression of the first metal lines deepened, the short yield worsened. Residual copper in areas where dishing and erosion from lower levels manifest could cause short circuits between wires. This result strongly suggests the planarity of under-layer Cu wiring should be less than 30 nm to get a 100% short yield.

The Cu dishing dependency with polishing pad hardness is shown in Fig. 2. Hardness is defined using the JIS K-6301. A hardness comparison was made between a formed polyurethane with Shore D of 51 and a non-formed polyurethane pad with Shore D of 71. Both pads formed lattice-like grooves. The harder pad can reduce the amount of dishing above a 20 um line width. But no difference in dishing below a 5 um line between the pads occurs. To further reduce dishing on narrow lines in less than a 5 um width, we evaluated three types of grooves on the stacked pad (Rodel IC1400) shown in Table 1, where other properties of the pads were kept the same. Both lattice-like and concentric circular grooves are commercially available as A21 and K-grooves from Rodel.

A Cu-AFP was improved using on a rotary Applied Materials Mirra CMP system. Hitachi Chemical HS-C series abrasive free slurry was used to polish copper films. We used a hydrogen peroxide aqueous solution (H_2O_2, 30 wt%) as the oxidizer. The mixture ratio was HS-C430: 70 vol% / oxidizer: 30 vol%. We also used a selective type barrier metal CMP slurry (the Hitachi Chemical HS-T series) that consisted of chemical agents and damage-free colloidal silica as an abrasive. The concentration of the oxidizer (H_2O_2, 3wt%) was fixed at oxidize: 8 vol%.

A KLA-Tencor High Resolution Profiler (HRP-100) was used to measure dishing and erosion, and an Emerald from Philips was used to measure the thickness of the copper.

Results and Discussion

First,we inquired into the polishing friction forces. Fig. 3 shows the dependence of the normalized friction force on the polishing pads adding deionized water to affect the temperatures of the pad surface. Friction force is defined as the polishing drag into which the carrier arm is loaded. This friction force was detected using a load cell. The temperature of the pad surface was measured using an infrared sensor. The down force was fixed at 21 kPa in this experiment. The friction forces were changed by the designs of the grooves and the flow of the deionized water. The friction force was a pronounced function of the design of the groove on the pads, increasing significantly as the groove varied from lattice-like to streamlined grooves and finally to concentric circular grooves.

Fig. 4 shows the Cu dishing comparison between the designs of the grooves on the polishing pads. The line density was the ratio of the line width to the pitch. The pitch was the width plus the oxide space. The use of a concentric circular groove pad increased the Cu dishing above a 90% line density.

Fig. 5 shows the dependence of copper dishing with pad formed lattice-like grooves on the removal thickness of blanket Cu film.The Cu thickness was 800 nm on the patterned wafer. The initial step height of the metal film was approximately equal to the trench depth. As polishing proceeded, the step height was gradually reduced. Dishing using a platen speed of 40 rpm was lower than that using a platen speed of 87 rpm. As the platen speed was lowered, the friction force increased, as shown in Fig. 3. Thus, we can say that a higher friction force can reduce Cu dishing. Dishing reaches its minimum value before the Cu film

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on the field is cleared. This result suggests an exposure to the barrier film increases dishing.

The Cu dishing as a function of the slurry flow comparison between the designs of the grooves on the polishing pads is shown in Fig. 6. There was a small difference in the Cu dishing between a slurry of 150 cc/min and 300 cc/min using lattice-like grooves pads. However, the lower slurry flow rate (150 cc/min) reduced the amount of Cu dishing less than 30 nm using the pad formed streamline grooves.

The pad surface features appear to play an important role in the amount of Cu dishing. The material removal mechanism of AFP is explained below.

(1) When CMP is done using AFP solutions, the metal surface is first treated by the oxidizer, and a thin oxide layer forms on the surface.

(2) Next, when a substance is supplied to make the oxide water-soluble, the reaction produced on the surface is mechanically removed by the polishing pad and the thickness of the oxide layer decreases.

(3) The part of the oxide layer that became thinner is again exposed to the oxidizer and the thickness of the oxide layer increases.

(4) This reaction is repeated as the CMP proceeds.

Judging from the results shown in Figs. 3 to 6, both the macroscopic and microscopic properties of a pad can impact on the patterned wafer performance. The friction force clearly reduces the dishing that occurs during the polishing, as mentioned in step (2) above. Thus, we can say that the design of the grooves is one of the most important factors in controlling the force. A higher than necessary force using something like a concentric circular groove pad can generate unwanted local heating that causes the etching of the Cu wiring during the polishing mentioned in step (3). We can control the force by changing the design of the grooves on the polishing pad.

Fig. 7 shows Cu thinning (dishing plus erosion) after a barrier polishing comparison between the designs of the grooves on the polishing pads. The amount of Cu thinning was lower with the pad formed streamline grooves. Using the streamline groove pad can reduce a metal loss of 20% on the Cu wiring compared to using the lattice-like groove pad. These planarity levels of less than 40 nm can meet the 0.1um technology target without doing extra intermediate oxide polishes for multi-level metallization.

Fig. 8 shows the Cu sheet resistance comparison between the designs of the grooves on the polishing pads. The Cu wiring is a 5 um width serpentine line. The sheet resistance using the pad formed streamline grooves was 10% lower than using the pad formed lattice-like grooves.

We demonstrated an improvement in the Cu AFP with a modified groove design pad to provide the optimized friction force, tuning the polishing condition at 0.13 um manufacturing and beyond.

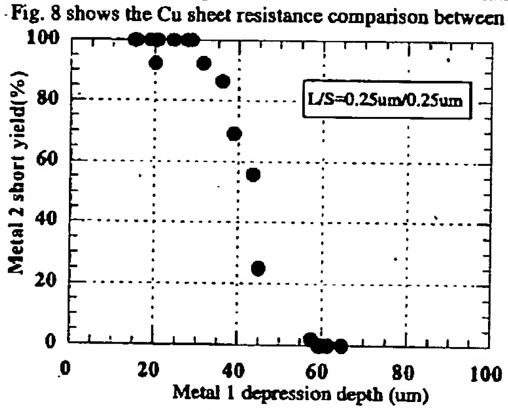

Fig. 1. Short yield of metal 2 as a function of metal 1 depression depth. A short yield worsened as the step height of metal1 increased.

Conclusion

A Cu AFP was improved using a modified groove design pad to optimize the friction force, which tunes the polishing condition. This method provides a post of less than 30nm on a 5 um Cu line of 95% density for patterned wafers of 800nm Cu thickness. Cu thinning (dishing plus erosion) on a 95% structure was less than 40 nm using a high selective barrier metal slurry. There was no need to do any extra intermediate oxide polishing. Electrical sheet resistance measurements on a 5 um array structure showed an improvement of 10% compared to the conventional AFP process. Therefore, this process is likely to meet next generation Cu interconnect requirements.

Acknowledgements

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References

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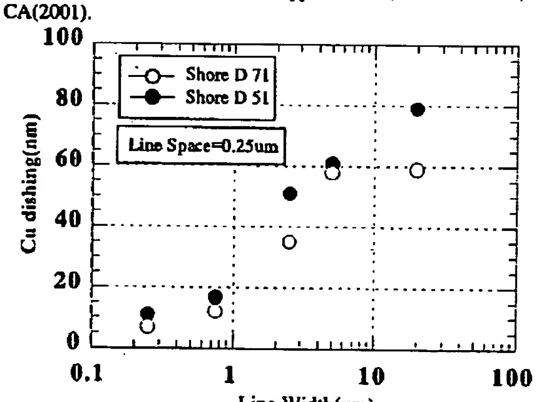

Fig. 2. Effect of polishing pad hardness on Cu dishing. A harder pad can reduce the amount of dishing above a 20 um line width.

Table 1.Types of grooves formed on polishing pads

	Sample	Grv.pitch	Grv.width	Contact area ratio
1	Lattice-like grv.	15 mm	2 mm	0.75
2	Concentric circular grv.	1.5 mm	0.2 mm	0.83
3	Streamline grv.	-	2 mm	0.84

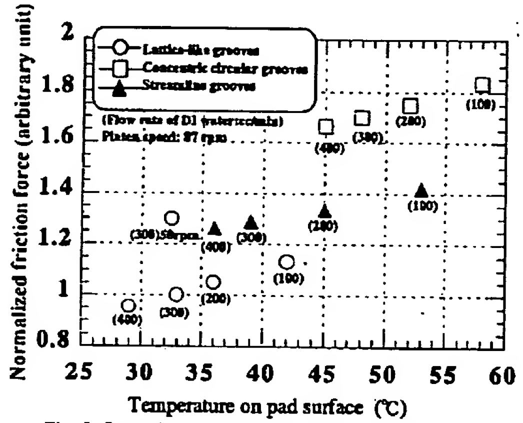

Fig. 3. Dependence of friction forces on polishing pads adding deionized water to affect the temperatures of the pad surface. The forces were changed by the design of the grooves and the flow of deionized water.

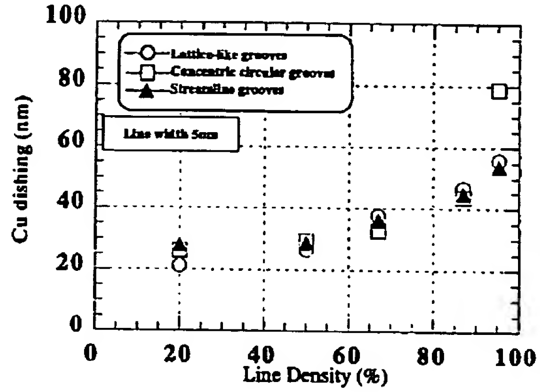

Fig. 4. Cu dishing comparison between designs of grooves on polishing pads. The amount of Cu dishing was higher using the pad formed lattice-like grooves above 90% density.

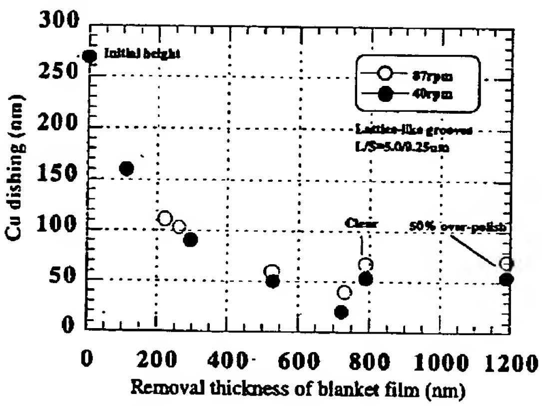

Fig. 5. Dependence of copper dishing using a pad formed lattice-like grooves on the removal thickness of blanket Cu film. As polishing proceeded, the step height was gradually reduced. Dishing with a platen speed of 40 rpm is lower than that using a platen speed of 87 rpm.

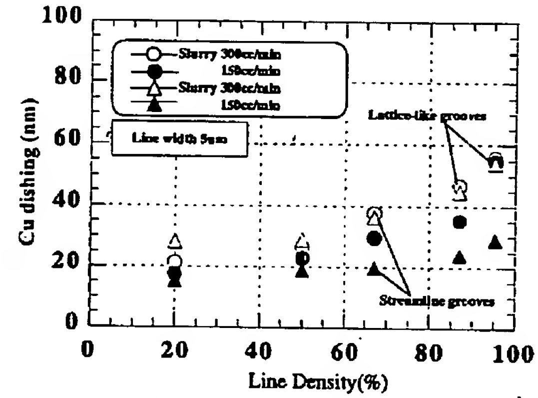

Fig. 6. Cu dishing as a function of slurry flow comparison between designs of grooves on polishing pads. Lower slurry flow (150cc/min) reduced the amount of Cu dishing using the pad formed streamline grooves.

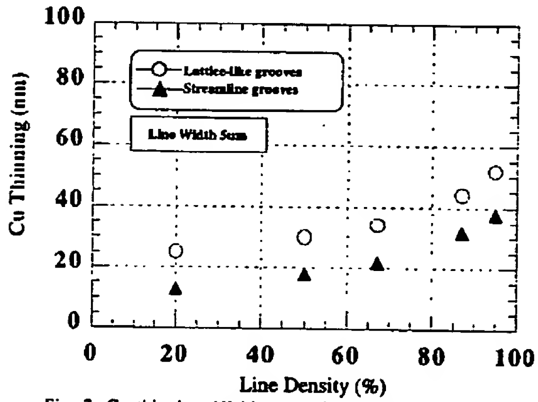

Fig. 7. Cu thinning (dishing+erosion) after barrier polishing comparison between designs of grooves on polishing pads. The amount of cu thinning was lower using the pad formed streamline grooves.

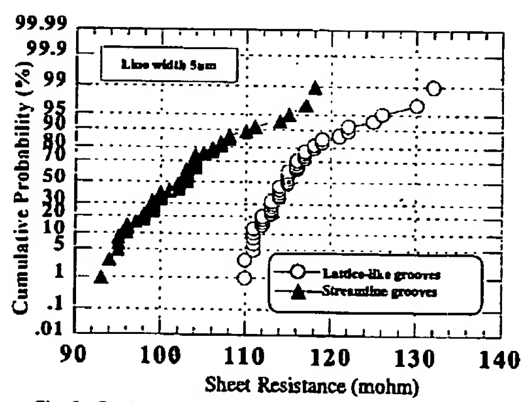

Fig .8. Cu sheet resistance comparison between designs of grooves on polishing pads.
Sheet resistance using the pad formed streamline grooves was 10% lower than using the pad formed lattice-like grooves.